THE LARVAL ECOLOGY OF *AËDES AUSTRALIS* (ERICHSON) (DIPTERA, CULICIDAE) IN THE SYDNEY AREA.

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(Plate vi; seven Text-figures.)

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Synopsis.

The distribution of the larvae of *A. australis* in the Sydney area was found to be correlated with the geological formation of the coastline, for the larvae occurred only in saltwater rock pools formed in sandstone rock platforms.

At Mackenzie Bay a series of six rock pools was studied to try to correlate egg hatching and larval mortality with the environmental factors of flushing, temperature, salinity and evaporation. Temperature did not affect larval mortality as the larvae could withstand a daily range in temperature of at least 27°F., a seasonal range in temperature of at least 54°F., and an hourly change in temperature of at least 9°F. However, salinity affected both egg hatching and larval mortality as first instar lavae were absent from pools in which the salinity of the water had increased beyond the mean value 4·6%, and fourth instar larvae could tolerate a salinity of up to 24% and a daily increase in salinity of 5·2%.

The percentages of occurrences of first and fourth instar larvae in these rock pools were 59 and 68 respectively, while larvae were absent from the pools in 25% of the examinations, 10% being due to flushing by heavy seas, 5% being due to flushing by rain water and 10% being due to drying of the pools. The significance of these findings is then discussed with regard to the ecology of this species.

Introduction.

The larvae of *Aëdes australis* (Erichson) (= *concolor* Taylor) are found in the Sydney area in sandstone rock pools in which the salinity varies (Mackerras, 1926; Woodhill, 1936). O'Gower (1959) was able to explain the presence of these larvae in such habitats by studying the oviposition behaviour of the female mosquito, but this study did not explain the absence of larvae from freshwater pools. To understand more fully the larval ecology of this species a series of six rock pools was studied at Mackenzie Bay to try to correlate larval mortality and emergence with the environmental factors of salinity, temperature, flushing and evaporation.

Methods.

The coastline of the Sydney area from the Hawkesbury River to Botany Bay was examined where physically possible for larvae of *A. australis* and all areas examined, together with all positive findings, were plotted on a distribution map.

The influence of the environmental factors of temperature and salinity on larval emergence and larval mortality was then studied in a selected series of six rock pools at Mackenzie Bay. These rock pools were examined at 0700 hours thrice weekly over a period of twelve months for the presence or absence of first instar larva and fourth instar larvae, and at the same time the salinity and the temperature of the water in each pool were measured. Concurrently at monthly intervals hourly changes in the temperature of the waters of these pools were recorded from 0700 hours to 2000 hours.

Temperatures were measured with a thermometer shielded against radiant heat and were read at the centres of the pools with the thermometer bulb one inch below the water surface. However, when the depths of the pools became less than one inch due to evaporation, temperatures were read with the thermometer case resting on the bottoms of the pools.

Water samples for salinity determinations were collected in tightly stoppered bottles and titrated within half an hour against N/10 silver nitrate using potassium dichromate as the indicator. Four determinations of each sample were made and the mean of these used for the salinity value.

The degree of exposure of each of the six pools to sunlight, salt spray and to wave action was noted, while such physical dimensions as area of the water surface, length of intersurface between water and rock surface, depth and volume were measured.

Results.

It can be seen from Figure 1 that the distribution of the larvae of *A. australis* between the Hawkesbury River and Botany Bay is continuous except along the coast line from Palm Beach to Long Reef. This is due to an outcrop of Narrabeen shales in

Fig. 1. The larval distribution of *Aëdes australis* (Erichson) in the Sydney area.

an area which is predominantly Hawkesbury sandstone, for weathering forms rock pools of varying shapes and sizes in rock platforms of sandstone, but not in those of shale. Thus the type of larval habitat occupied by this species is not available in areas where there are outcrops of shale.

Tri-weekly examinations of the rock pools over the twelve-month period showed: (i) first instar larvae were not present in any of the pools in which the salinity had increased beyond the value, mean 4·6%, variance 0·12, and in two instances over this period fourth instar larvae died when the salinity reached an approximate value of 25% (less than 24% in Pool A with a daily increase in salinity of 5·2% and 25·7% in Pool B with a daily increase in salinity of 1·4%); (ii) the percentages of occurrences of first and fourth instar larvae were 59 and 68 respectively; (iii) larvae were absent from these pools in 25% of the examinations, 10% being due to flushing by heavy seas, 5% being due to flushing by rain water and 10% being due to drying of the pools.

The degree of exposure of each of the six rock pools to sunlight, salt spray and to wave action is given below; figures are presented of the hourly changes in temperatures of the pools for a sunny day in each of the months January, April, July and October; the physical dimensions of the pools are shown in Table 1; and the position of each pool in the study area is shown on Plate vi.

Pool A is approximately seven feet above mean high tide, but is placed in such a position relative to the surf that moderate seas at high tide flush the pool with sea water. During the stormy winter months this flushing is sufficiently regular to allow such marine animals as the worm *Galeolaria caespitosa* and the anemone *Oulactis mucosa* to colonize the pool temporarily. At other times the pool receives a considerable amount of salt spray, which, together with a high rate of evaporation of water due to the large surface area of the pool and its shallow depth, can cause a daily increase in salinity of the water of 5·2%. The pool is exposed to sunlight from sunrise to midday over the whole year and the resulting hourly changes in the temperature of the water can be seen in Figure 2.

TABLE 1.

Dimensions of Six Selected Rock Pools.

Pool.	Area. (Square Feet.)	Circumference. (Feet.)	Mean Depth. (Inches.)	Volume. (Cubic Feet.)
A	31·6	27·0	2·0	5·3
B	2·8	8·4	3·8	0·8
C	3·8	8·8	4·4	1·4
D	11·3	21·4	1·7	1·6
E	12·2	25·8	14·4	14·6
F	2·7	8·3	2·7	0·6

Pool B is on the same platform as Pool A, but further from the edge of the surf. Thus only heavy seas at high tide flush the pool with sea water. Although the pool is exposed to considerable amounts of salt spray at other times, the daily increase in salinity due to evaporation was low (1·4%), for the pool is sunlit for only a few hours after sunrise in winter and thus the hourly change in temperature was slight and the daily maximum temperature was low (Figure 3).

Pool C is also on the same platform as the two former pools, but further from the edge of the surf and at a slightly lower level. Thus only heavy seas at high tide can flush it with salt water, but it is exposed to salt spray. Due to its position relative to run-off from domestic effluent the water was frequently polluted with organic matter. The pool is exposed to sunlight from sunrise to midday over the whole year and the effect of this can be seen in the hourly change in the water temperature (Figure 4).

Pool D, although on the same rock platform as the three former pools, is at a considerable distance from the edge of the surf and is therefore only rarely flushed with sea water, but is exposed to a considerable amount of salt spray. This pool is exposed to sunlight from sunrise until the sun sinks below the low cliffs behind it at about 1500 hours, and this exposure, together with the large surface area and the shallow depth of the pool, resulted in high temperatures, large hourly changes in temperature (Figure 5) and a high rate of evaporation. Thus the pool was dry 64 days during the period October to March inclusive, but the salinity did not exceed 4·7% during this period.

Pool E is on a sheltered rock platform above and beyond the edge of the surf. Thus it receives only a fine salt spray mist even in huge seas. The pool is exposed to sunlight for about four hours in the middle of the day in summer. However, due to the small surface area of the pool relative to its volume, hourly changes in the

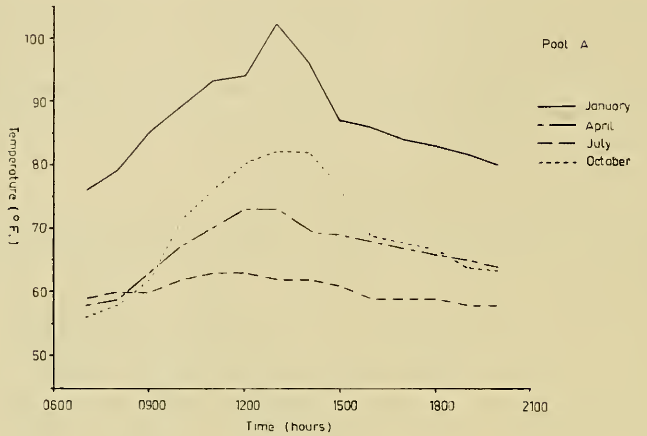

Figure 2.

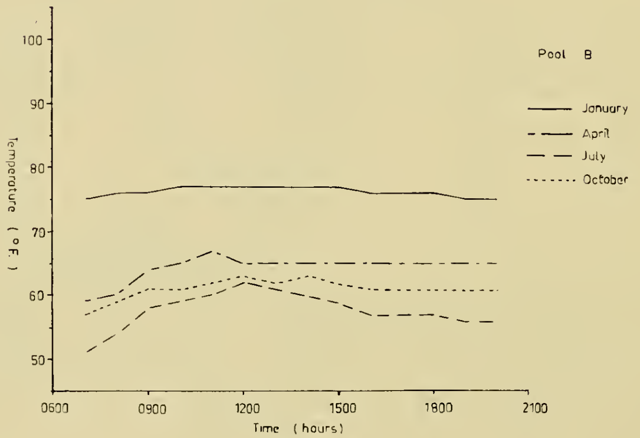

Figure 3.

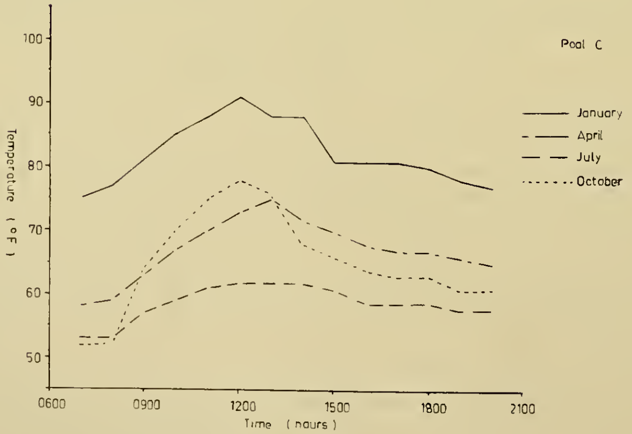

Figure 4.

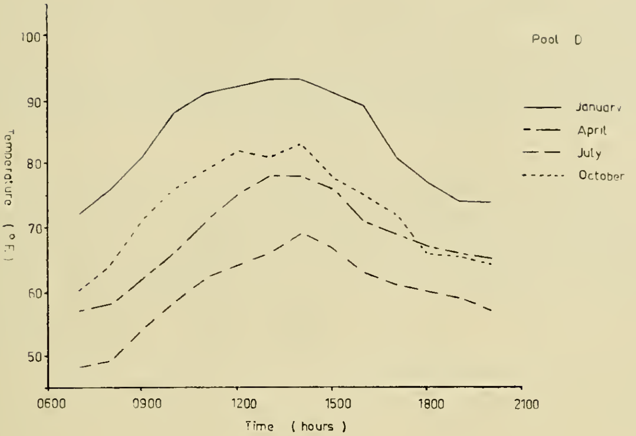

Figure 5.

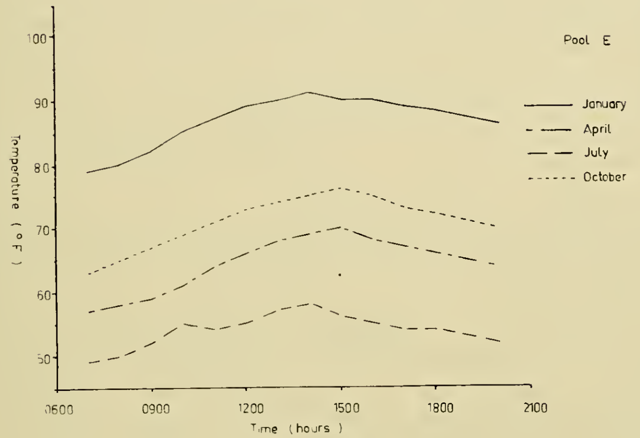

Figure 6.

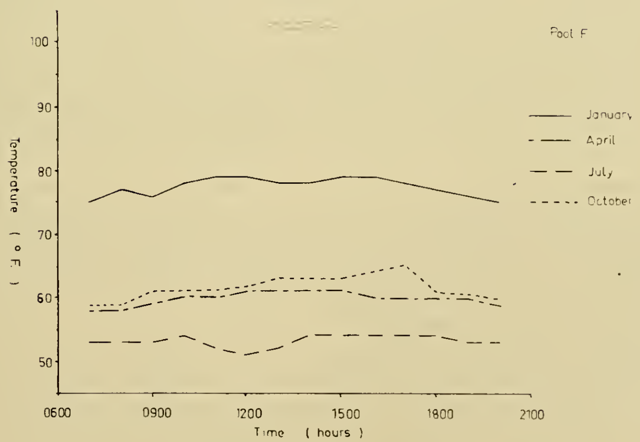

Figure 7.

Figs 2 to 7. Hourly changes in the temperatures of the waters of Pools A to F respectively for the months January, April, July and October.

temperature of the water were small (Figure 6) and never during the period of study did the pool dry out.

Pool F is on a small rock platform above the surf and thus receives only a fine salt spray mist, and, as it is continuously shaded all the year by overhanging rock, the hourly changes in the temperature of the water were slight (Figure 7).

Discussion.

A study of the hourly changes in temperature of each of the six rock pools for the months January, April, July and October (Figures 2, 3, 4, 5, 6 and 7) shows first that there was a correlation between the physical dimensions of the pools and the hourly changes in water temperatures; second that in all pools except B and F the water temperature rose to a maximum at or about midday; and third, that there was a striking seasonal variation in the water temperatures. As no mortalities due to high or low temperatures were recorded in any of the pools, the larvae must be able to tolerate a daily range of temperature of at least 27°F. (Figure 2: from 75°F. to 102°F.), a seasonal range in temperature of at least 54°F. (Figures 5 and 1: from 48°F. to 102°F.), and an hourly change in temperature of at least 9°F. (Figure 1: January, 1400 hours to 1500 hours).

The ability of the larvae of *A. australis* to tolerate these relatively large changes in temperature is of obvious ecological importance to this species, for the salt-water rock pools, in which these larvae occur, lack either emergent or overhanging vegetation which usually shades fresh-water rock pools. Thus water temperature, although it may be a factor which limits the larval distribution of those species breeding in fresh-water rock pools, appears to have little influence in limiting the distribution of *A. australis*, and the larvae appear to be physiologically adapted to such an environment.

Tri-weekly salinity determinations in all six rock pools showed that first instar larvae only occurred in water which had a mean salinity of less than 4·6%. Thus either rain water or sea water can hatch the eggs of *A. australis*. It was also shown that fourth instar larvae can tolerate a daily increase in salinity of 5·2% up to a maximum of approximately 24%, and this maximum agrees closely with the 20% salinity which Woodhill (1936) showed did not affect survival but which did affect pupation. Finally it was noted that over the twelve-month period deaths of larvae due to high salinities occurred only twice. It may therefore be concluded that the larvae of *A. australis* are physiologically adapted to a salt-water rock-pool environment and that salinity, apart from limiting egg hatching, does not affect the larval population.

During the period of study the rock pools were dry in 10% of the examinations and in all cases the larvae died from desiccation and not from the increase in salinity. For example, Pool D, which has a large surface area, a shallow depth and a small volume, was empty of water 28% of the time during the period October to March inclusive, and the maximum salinity recorded during this period was 4·7%. Thus one hazard to the survival of the larvae of *A. australis* is the physical drying out of the rock pools from evaporation.

The unsuccessful colonization of Pool A by *Galeolaria* and *Oulactis* indicates that this pool was regularly flushed with sea water for at least some period during this study; otherwise these invertebrates could not have become established. Thus the constant flushing of the more exposed rock pools by heavy seas in winter, which accounted for 10% of the examinations being negative for larvae, is another hazard to the survival of the larvae of *A. australis*.

The widespread simultaneous hatching of first instar larvae which invariably closely follows the filling of dry rock pools with rain water (O'Gower, 1958) indicates that the egg stage must be resistant to desiccation. Therefore the drying out and the flushing of rock pools by rain water, although accounting for 15% of the examinations being negative for larvae, did not destroy the breeding potential of the pools. But, as flushing by rain water did eliminate breeding in 5% of the examinations, then it must be another hazard to breeding by *A. australis*.

The above, together with the oviposition studies of Woodhill (1941) and O'Gower (1959), in which the presence of larvae of *A. australis* in salt-water rock pools could be explained but not their absence from fresh-water rock pools, indicates that further studies on the physiology of this species should be made to try to determine which factors of the environment limit the ecological distribution of this species to salt-water rock pools. It seems probable, however, that the following adult behaviour patterns tend to limit the dispersal of the adult mosquitoes away from their ecological habitats. These patterns are: the apparent reluctance to "take wing" in a resting site after being disturbed; the apparent lack of an appetitive drive of migration; the apparent limitation of the blood-feeding drive to periods of low wind velocity; the apparent movement of blood-fed mosquitoes back to the salt-water rock-pool habitat during the early morning off-shore breezes; and the resting stance of the adult in which the body is held very close to the resting surface (O'Gower, 1958).

It therefore seems likely that the ecological distribution of the larvae of *A. australis* in salt-water rock pools is due to (i) the oviposition behaviour of the adult mosquito (O'Gower, 1959; Woodhill, 1941), (ii) behaviour patterns of the adult which tend to limit the dispersal of the population away from this habitat (O'Gower, 1958), (iii) physiological adaptations of the larvae to varying salinities and temperatures, (iv) the lethal effects of distilled water on first instar larvae (Woodhill, 1941), (v) undetermined behaviour patterns of the larvae which may place them at a disadvantage in fresh-water rock pools, and (vi) the ability of the eggs to withstand long periods of drought.

Acknowledgements.

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EXPLANATION OF PLATE VI.

Mackenzie Bay showing the positions of the six rock pools.